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Plant biogeography, endemism and vegetation types of Dena Mts, Zagros, West Iran

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Abstract

Questions: The highest mountain peak of Zagros is located in the Dena mountain system (4409 m a.s.l.), which is identified as the second richest center of plant endemism of Zagros. In this study we (1) investigate floristic affinities of Dena Mts to adjacent mountain ranges based on the endemic species of the Iranian Plateau, (2) identify the species reaching the subnival zone, and (3) characterize the plant communities of the subnival zone of Dena Mts. **Study area:** Dena Mts is a calcareous mountain system in southern Zagros, Iran. **Methods:** The list of taxa endemic to the Iranian Plateau present also in Dena Mts was taken from our previously published data. Novel vegetation data were collected using the methodology of Braun-Blanquet. Classification was carried out in JUICE using the Modified TWINSPAN method. **Results:** Of the 242 taxa endemic to the Iranian Plateau present in Dena Mts, 22 taxa are endemic to the latter. Dena Mts have the strongest floristic affinity with the Yazd-Kerman massif, with which they share 84 taxa compared to 51 taxa shared with Alborz, 37 taxa shared with the Azerbaijan Plateau, and 15 taxa shared with Kopet Dagh-Khorassan. In Dena Mts, 38 taxa reach the subnival zone, most of them being endemic to the Iranian Plateau (68%). From scree habitats in the subnival zone, two new plant associations are described, *Aethionemetum umbellati* and *Zerdanetum anchonioidei*. These constitute a newly described alliance *Galion pseudokurdici*, classified within the class *Didymophyso aucheri-Dracocephaletea aucheri*. **Conclusions:** Although Dena Mts lie within a protected area, this will not prevent shrinking of alpine and subnival habitats due to global warming. Consequently, strong attention to the conservation of all range-restricted species of this mountain system, especially of alpine and subnival species, is highly recommended.

Taxonomic reference: Flora of Iran (Assadi et al. 1989–2021) and, for families not yet covered in the previous source, Flora Iranica (Rechinger 1963–2015).

Keywords

biogeography, conservation, Dena Mts, endemism, subnival zone, vegetation, Zagros

Introduction

Global biodiversity hotspots, many of which are located in mountainous areas, are known as regions with high conservation priorities due to their rich endemic diversity and, at the same time, high pressure from human activities (Myers et al. 2000; Mittermeier et al. 2005, 2011). One such hotspot is the Irano-Anatolian biodiversity hotspot, which is a mountainous region in South-West Asia with very heterogenous climate and topography (Zohary 1973; Djamali et al. 2012) and, consequently, harboring a rich endemic diversity, especially at high elevations (Mittermeier et al. 2011; Noroozi et al. 2021). The Irano-Anatolian biodiversity hotspot includes several areas of endemism that are strongly associated with the major mountain ranges (Noroozi et al. 2019a, 2019b).

Zagros mountain range, the most extensive mountain range of Iran (Figure 1), is one of the richest areas of endemism of the region with numerous centers of endemism, mostly located in areas with very high elevations (Noroozi et al. 2019a). Among those areas, Dena Mts are the highest mountain system, reaching 4409 m a.s.l. at its highest peak (Figure 1). Dena Mts are the second-richest center of plant endemism in Zagros and the fourth-richest in Iran (Noroozi et al. 2019a). The Austrian botanist Theodor Kotschy (1813–1866), the most important collector of natural history objects active in the nineteenth century in South-West Asia (Edmondson and Lack 2006), was the first botanist to collect plants from the alpine and subnival zones of Dena Mts (in 1842), and many of the numerous collected plants were described as new species by Edmond Boissier in his Flora Orientalis (Boissier 1867–1884). Although Dena Mts have been frequently visited by national botanists, only few botanists have ascended to the high alpine and subnival zones after Kotschy, so that data pertaining to these elevation zones remained scarce and became potentially outdated. This is also the case for the "Flora of Dena Mts." (Jafari Kokhedan 2003). Despite the prominent role as a center of biodiversity in Zagros, endemic diversity, biogeography, vegetation as well as conservation aspects of Dena Mts have only been poorly studied.

The subnival flora is an important component in SW Asia contributing a high proportion of endemics that are highly threatened (Noroozi et al. 2011). Although exploration of the alpine and subnival flora of Dena Mts dates back to Kotschy, a thorough survey of it has been lacking. Connected to the poor exploration of the alpine zone, little is known about the vegetation types in this area, especially in a phytosociological context.

As a basis for putative conservation strategies, we here provide a biogeographic characterization of Dena Mts with a focus on the particularly poorly studied high elevation zones. To this end, we use the following approaches: (1) The floristic affinities and thus biogeographic connections of Dena Mts to other mountain ranges of the region are analyzed; (2) a full account of the subnival plant diversity of Dena Mts is given; (3) plant communities from the subnival zone are described and classified.

Study area

Dena Mts is a calcareous mountain system in southern Zagros, ca. 60 km long and ca. 10 km wide. Nearly 100 peaks exceed 4000 m a.s.l., with the highest one reaching 4409 m a.s.l., being the highest summit of the entire Zagros mountain range (Figure 1). Dena Mts have a Mediterranean precipitation regime with cold-wet winters and warm-dry summers (Figure 2). Western slopes receive more precipitation than eastern slopes, and in the alpine zone the annual precipitation exceeds 1000 mm (Jafari Kokhedan 2003).

The main vegetation types of the study area can be summarized as follows (see Noroozi et al. 2020 and references therein):

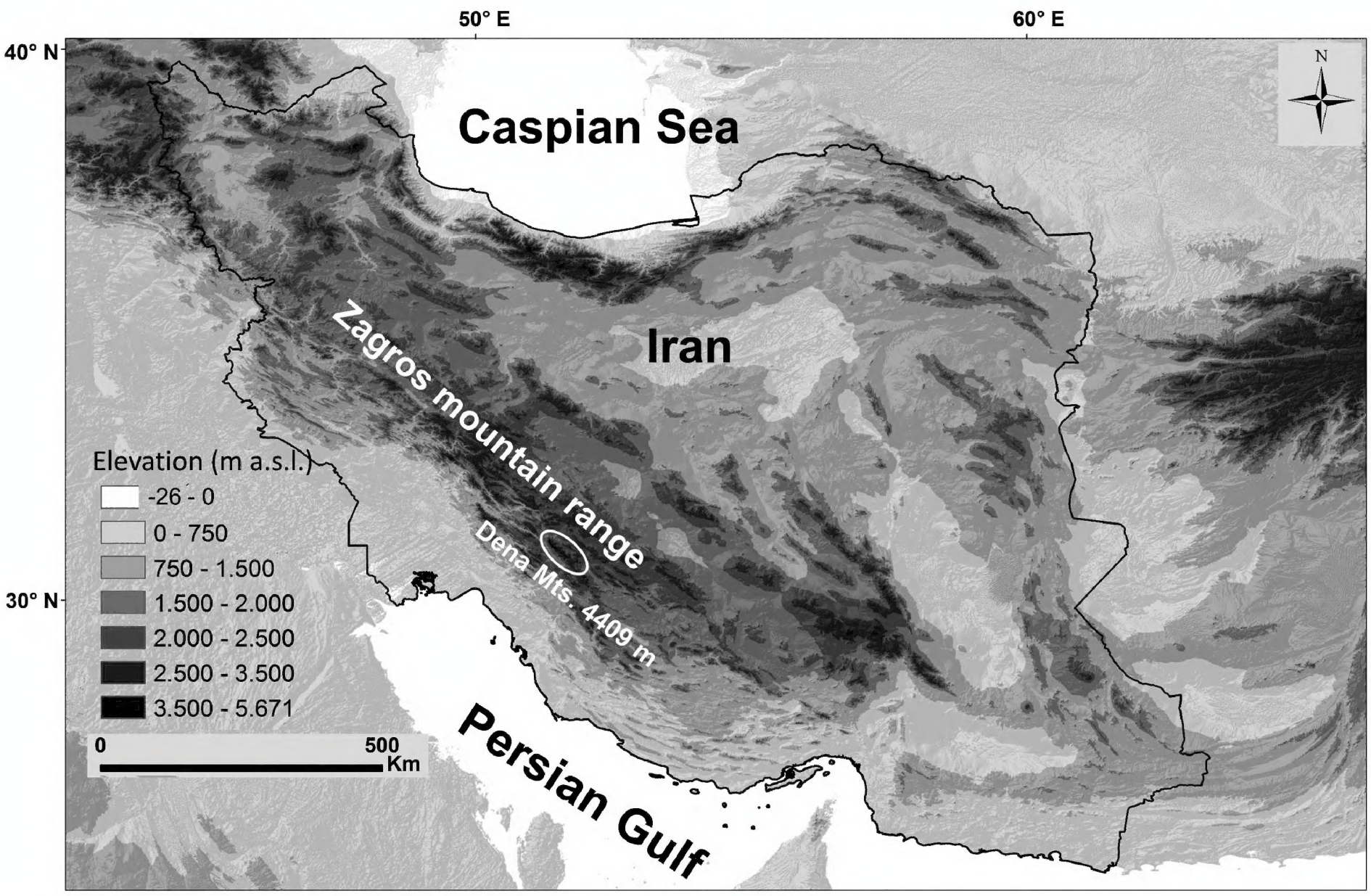

Figure 1. Location of Dena Mts in the Zagros mountain range in Iran.

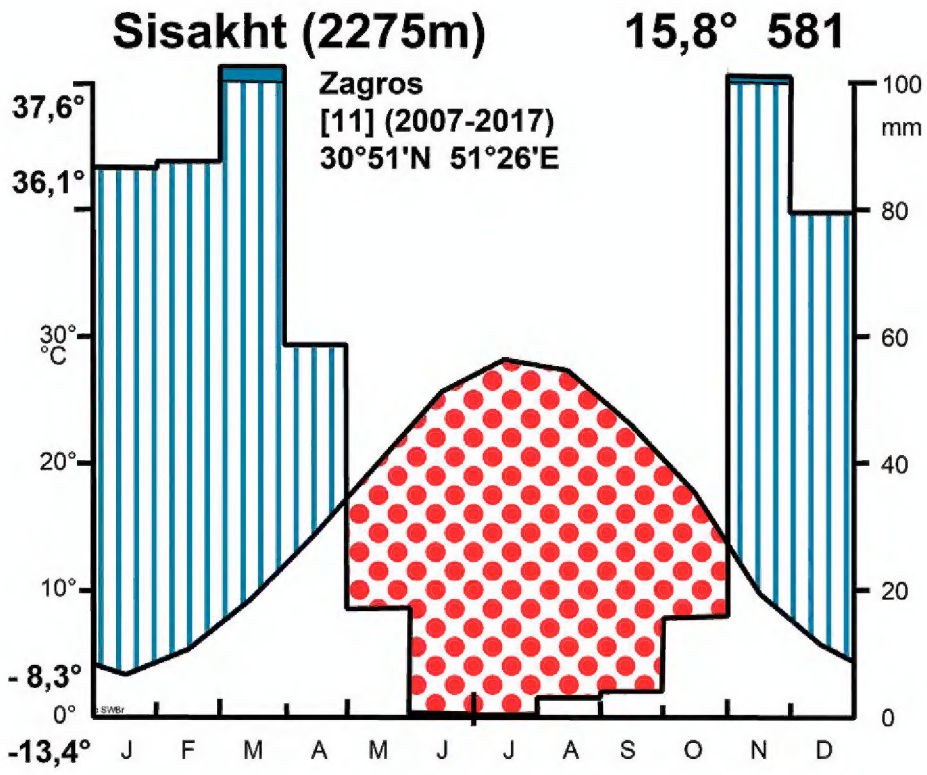

Figure 2. Climate diagram of the study region.

***Quercus* woodlands** (Figure 3A) occupy the montane zone of Dena Mts, especially on the western slopes up to 2700 m a.s.l. These woodlands are dominated by *Quercus* species, especially *Q. brantii* (Jafari Kokhedan 2003). Other frequent shrubs and trees are *Cotoneaster luristanica*, *Daphne mucronata*, *Lonicera nummularifolia*, *Pistacia khinjuk* and *Rhamnus kurdica*.

Subalpine tall-umbelliferous vegetation types (Figure 3B) mostly cover steep slopes with scree in elevations ranging from ca. 2500 to 3500 m a.s.l. In term of physiognomy, environmental features and species composition, they can be classified in the provisional class *Prangetea ulopterae*, described from Alborz mountain range (Klein 1988, 2001). The most dominant species of this vegetation type in Dena Mts is *Ferulago angulata* (Figure 3B).

Chasmophyte vegetation types (Figure 3C, D) have a high elevational amplitude from the montane to the subnival zone. Characteristic species in these habitats include *Arenaria minutissima*, *Dielsiocharis kotschyi*, *Dionysia bryoides* (Figure 3C), *D. termeana* (Figure 3D), *Graellsia saxifragifolia*, *Pentanema multicaule*, *Rhamnus cornifolia*, and *Tanacetum kotschyi*.

Subalpine and alpine thorn-cushion grasslands (Figure 4A, B) are the main formation of the subalpine and alpine zone, having more developed soils compared to other communities of these zones. In the subalpine zone, up to 3500 m a.s.l., the main dominant thorn-cushion species is *Astragalus brachycalyx*, mostly accompanied by *Bromus tomentellus*, *Daphne mucronata*, *Euphorbia polycaulis*, *Fritillaria imperialis*, and *Tulipa systola*. In the alpine zone, from ca. 3500 m a.s.l. up to ca. 4100 m a.s.l., this formation is dominated by *Astragalus murinus* (Figure 4A, B) and *A. myriacanthus*. Other accompanying species are *Acantholimon melananthum*, *Arenaria persica*, *Arnebia euchroma*, *Cousinia bakhtiarica*, *Euphorbia microsciadia*, *Marrubium astracanicum*, *Micrantha multicaulis*, *Phlomis anisodonta* subsp. *occidentalis*, *Scorzonera subaphylla*, and *Tanacetum dumosum*.

Alpine snowbeds (Figure 4C, D) are mostly found at elevations between ca. 3500 m a.s.l. and 4100 m a.s.l., where snow cover can persist till July and August. The growing season of these vegetation types is short, and most of the species are small hemicryptophytes. Structure and composition (mostly at the generic level) of these communities are the same as those from Alborz, which belong to the order *Taraxaco brevirostris-Polygonetalia serpyllacei*. The most important character species of the order present in Dena Mts is *Polygonum serpyllaceum*. Other characterstic species in the region are *Arenaria balansae*, *Plantago atrata*, *Primula capitellata*, and *Ranunculus elymaiticus* (Figure 4C, D).

Alpine and subnival scree vegetation types (Figure 5) occur, where the ground is mostly covered by scree and big stones. They harbor only scattered vegetation and have a low species richness. Phytosociologically, these vegetation types belong to the class *Didymophyso aucheri-Dracocephaletea aucheri* described from Alborz and mountains of NW Iran (Noroozi et al. 2014). Character species of this class occurring in Dena Mts are *Didymophysa aucheri* (rare), *Elymus longearistatus*, *Astragalus melanodon* (Figure 5A), *Bromus frigidus* (Figure 5B), *Euphorbia aucheri* (Figure 5C), *Galium pseudokurdicum* (Figure 5D), *Physoptychis gnaphalodes* (Figure 5E), and *Stachys obtusicrena* (Figure 5F). The highest elevations of this mountain system, above ca. 4100 m a.s.l., are mostly covered with subnival scree vegetation types.

Methods

The list of taxa (species, subspecies and varieties) endemic to the Iranian Plateau and also present in Dena Mts was prepared using the list of all endemic vascular plant species of Iran published by Noroozi et al. (2019b) and our updated data (Table 1). Presence of these taxa in the adjacent mountain ranges, i.e., the Azerbaijan Plateau, Alborz, Kopet Dagh, and Yazd-Kerman, was used to quantify the floristic connections between Dena Mts and these mountain ranges. To explore the flora and vegetation of the subnival zone, an expedition dedicated to the high elevations of this mountain was undertaken in summer 2019. The plots were taken at subnival scree sites at elevations above 4100 m a.s.l. The alpine grasslands and subnival scree vegetation types are easily distinguishable in this area. Vegetation data from 19 plots, each 10 m × 10 m, were collected following the methodology of Braun-Blanquet (Braun-Blanquet 1964; Dengler et al. 2008). The proportional covers of the vegetation, scree, soil, and rock were estimated in each plot. The plot data were stored in Turboveg (Hennekens and Schaminée 2001). Classification was carried out in JUICE version 7.1 (Tichý 2002) using the Modified TWINSPAN and four cutlevel values (0%, 5%, 25%, 50%). A synoptic table was constructed based on the percentage frequency and fidelity of the species in each described association. We followed the phytosociological nomenclature code (Theurillat et al. 2020) to describe and propose new syntaxa. Associations were delimited according to Willner (2006). We used the phi value as fidelity measure and a threshold of 0.3. A synoptic table showing the character species of both the three alliances previously described for high alpine and subnival scree vegetation types of the Iranian Plateau and the alliance newly described in this paper is presented.

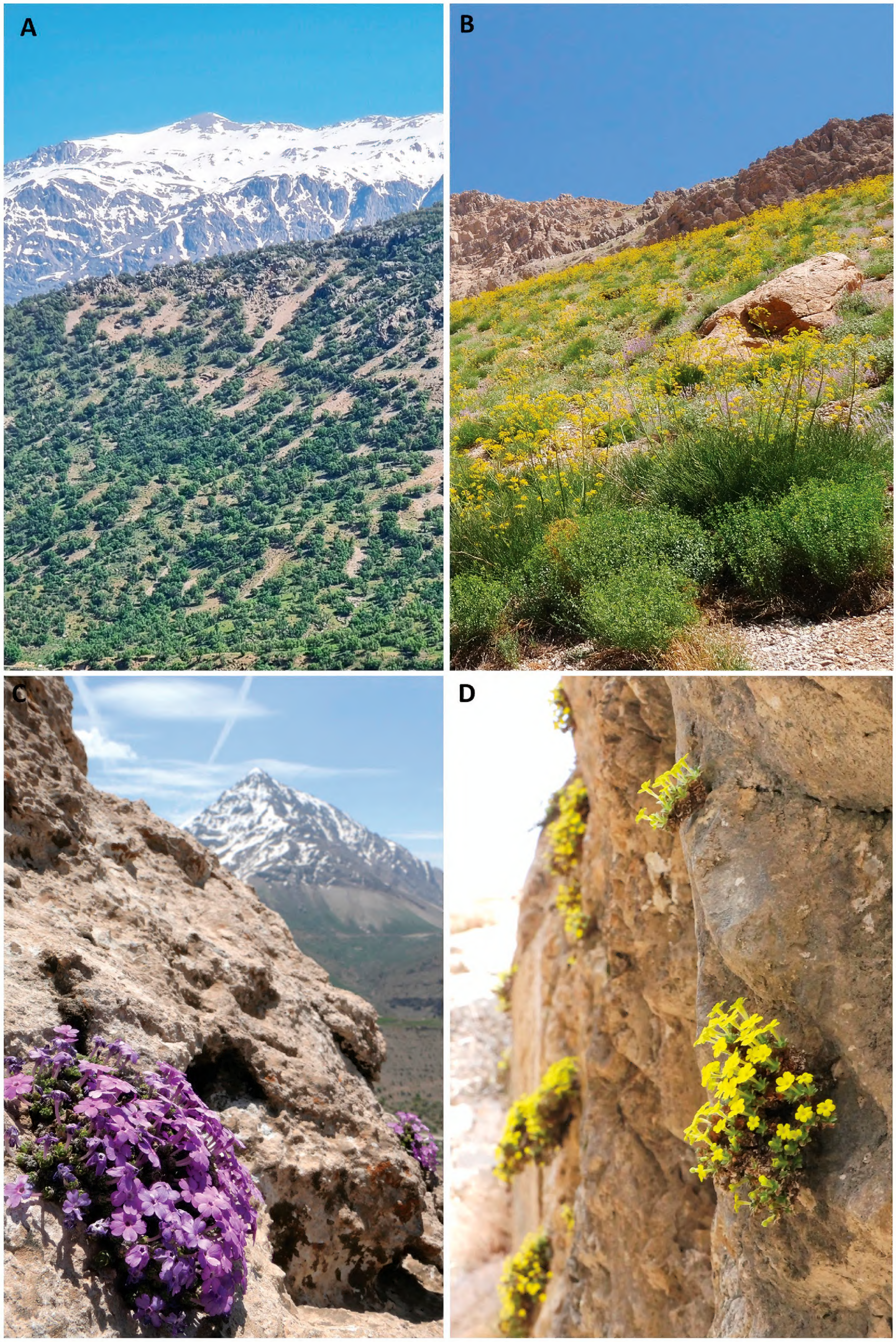

Figure 3. A) *Quercus brantii* woodlands (2000–2600 m a.s.l.). **B)** Umbelliferous vegetation types and *Ferulago angulata* as dominant species (2500–3500 m a.s.l.). **C)** Chasmophyte habitats, *Dionysia bryoides* (2800 m a.s.l.). **D)** Chasmophyte habitats, *Dionysia termeana* (2500 m a.s.l.).

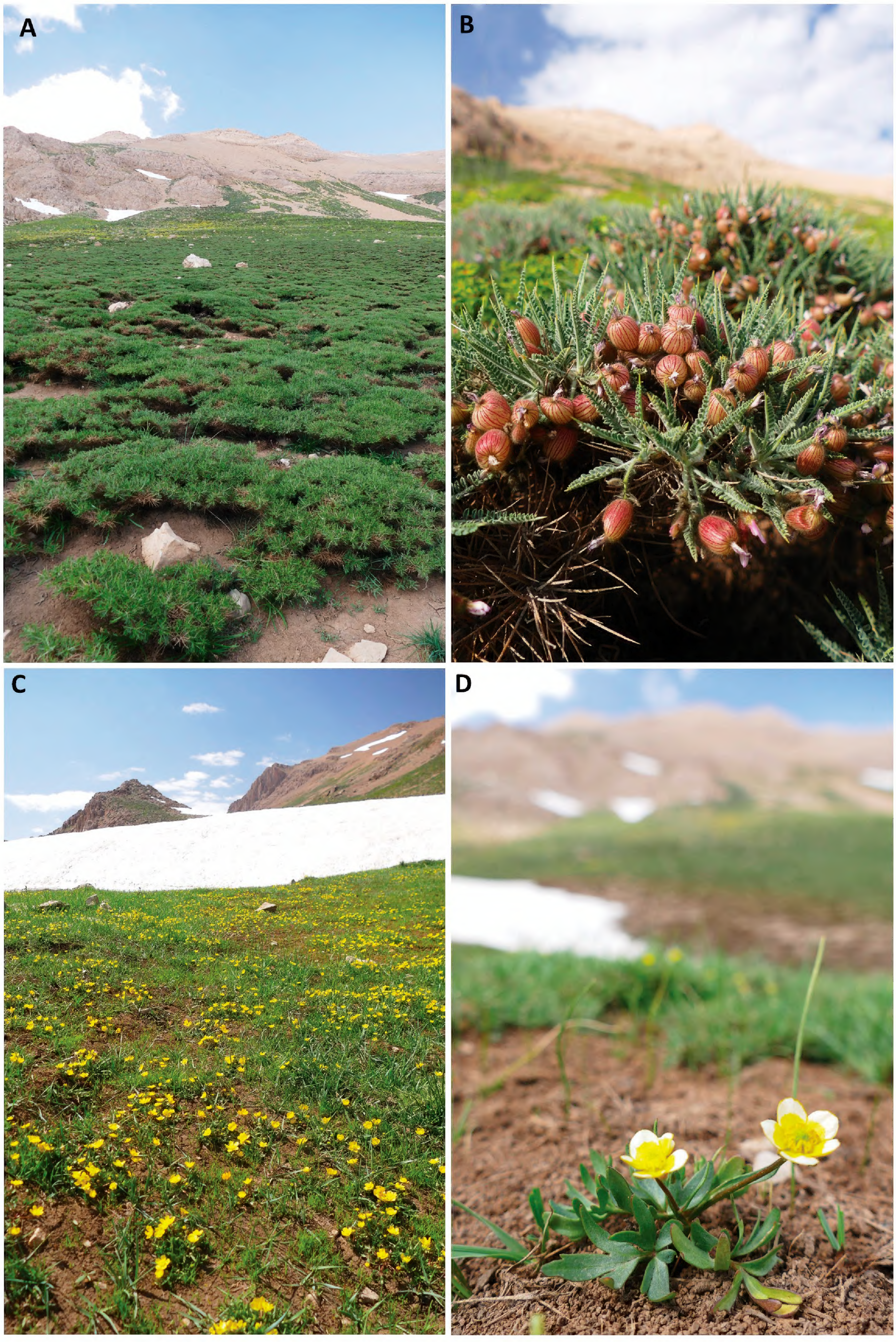

Figure 4. A, B) Thorn-cushion grasslands and *Astragalus murinus* as dominant species (3800 m a.s.l.). **C, D)** Snowbed vegetation types and *Ranunculus elymaiticus* as dominant species (3800 m a.s.l.).

Figure 5. Subnival scree vegetation types (4100–4409 m a.s.l.). **A)** *Astragalus melanodon* (4150 m a.s.l.). **B)** *Bromus frigidus* (4200 m a.s.l.). **C)** *Euphorbia aucheri* (4200 m a.s.l.). **D)** *Galium pseudokurdicum* (4150 m a.s.l.). **E)** *Physoptychis gnaphalodes* (4250 m a.s.l.). **F)** *Stachys obtusicrena* (4200 m a.s.l.).

Table 1. Endemic taxa of the Iranian Plateau recorded in Dena Mts. For each species, the following information is provided: family, distribution in different areas of endemism (Al: Alborz; Az: Azerbaijan Plateau; Ke: Yazd-Kerman; Ko: Kopet Dagh-Khorassan; Za: Zagros, endemics of Dena Mts given in bold) based on Noroozi et al. (2019b), elevational range in the entire geographical range of the species, and main habitat types (Alp. Scree: Alpine Scree; Chasm.: Chasmophytic vegetation; M Grass.: Montane Grasslands; Oak W.: Oak Woodland; Subn. Scree: Subnival Scree; Th.-Cu.: Thorn-Cushion vegetation; Umb.: Umbelliferous vegetation).

Species	Family	Distribution	Elevation range (m)	Main Habitat
Allium austroiranicum R.M. Fritsch	Alliaceae	Za, Ke	1700–3300	Umb., Th.-Cu.
Allium brachyodon Boiss.	Alliaceae	Za, Ko	3000–3200	Th.-Cu.
Allium kazerouni Parsa	Alliaceae	Za	1660–2900	Th.-Cu.
Allium kotschyi Boiss.	Alliaceae	Za, Ke	2500–3600	Th.-Cu.
Kochia prostrata (L.) Schrad. var. *alpina* Bornm.	Amaranthaceae	Za	2500–3000	Th.-Cu.
Astrodaucus persicus (Boiss.) Drude in Engler & Prantl	Apiaceae	Za, Al, Az, Ko	1000–2750	Oak W., Th.-Cu.
Dorema aucheri Boiss.	Apiaceae	Za, Ke	1700–3250	Umb., Th.-Cu.
Echinophora cinerea (Boiss.) Hedge & Lamond	Apiaceae	Za	2000–3300	Umb., Th.-Cu.
Ferula microcolea (Boiss.) Boiss.	Apiaceae	Za, Al, Az	1600–3050	Umb.
Ferulago angulata (schlecht.) Boiss.	Apiaceae	Za, Al, Az, Ke, Ko	2000–3700	Umb.
Ferulago carduchorum Boiss. & Haisskn.	Apiaceae	Za, Az, Ke	1700–3990	Umb.
Ferulago contracta Boiss. & Hausskn.	Apiaceae	Za, Ke	1700–2500	Umb.
Johreniopsis scoparia (Boiss.) Pimenov	Apiaceae	Za	2370–3000	Umb.
Leutea cupularis (Boiss.) M. Pimen.	Apiaceae	Za, Al	1800–3700	Umb.
Pimpinella deverroides (Boiss.) Boiss.	Apiaceae	Za	1500–3500	Umb., Th.-Cu.
Pimpinella dichotoma (Boiss. et Hausskn.) Wolff	Apiaceae	Za, Ke	1500–2750	Umb., Th.-Cu.
Pseudotrachydium kotschyi (Boiss.) Pimenov & Kljuykov	Apiaceae	Za	1950–3900	Th.-Cu., Alp. Scree
Rhabdosciadium aucheri Boiss.	Apiaceae	Za	1830–3960	Th.-Cu., Alp. Scree
Semenovia dichotoma (Boiss.) Manden.	Apiaceae	Za	2800–4200	Th.-Cu.
Semenovia frigida (Boiss.) Hausskn.	Apiaceae	Za, Ke	2400–3500	Th.-Cu.
Semenovia tragioides (Boiss.) Manden.	Apiaceae	Za, Al, Az, Ko	1500–3550	Th.-Cu.
Tetrataenium lasiopetalum (Boiss.) Manden.	Apiaceae	Za	2000–4000	Umb., Alp. Scree
Thecocarpus meifolius Boiss.	Apiaceae	Za, Ke	1500–3200	Th.-Cu.
Trachydium depressum Boiss.	Apiaceae	Za, Al, Ke	2100–3800	Th.-Cu.
Trachydium kotschyi (Boiss.) Boiss.	Apiaceae	Za	2000–3900	Th.-Cu.
Zeravschania aucheri (Boiss.) Pimenov	Apiaceae	Za, Al, Az	1300–3300	Th.-Cu.
Bellevalia heweri Wendelbo	Asparagaceae	**Za**	2200–2300	Wetland
Ornithogalum pycnanthum Wendelbo	Asparagaceae	Za	2400–3200	Th.-Cu.
Centaurea persica Boiss.	Asteraceae	Za	1550–3000	Oak W.
Cephalorrhynchus microcephalus (D.C.) Schchian	Asteraceae	Za, Al, Az	700–2800	Oak W.
Cicerbita polyclada (Boiss.) Beauverd	Asteraceae	**Za**	3300–3500	Oak W.
Cirsium bracteosum DC.	Asteraceae	Za, Ke, Al, Az	1800–3200	Oak W., Th.-Cu.
Cirsium spectabile DC.	Asteraceae	Za, Ke	1750–3000	Th.-Cu.
Cousinia albida DC.	Asteraceae	**Za**	2300–2600	Th.-Cu.
Cousinia amplissima (Boiss.) Boiss.	Asteraceae	Za, Al, Az	1000–2300	Oak W., Th.-Cu.
Cousinia araneosa DC.	Asteraceae	Za, Ke	1653–3600	Th.-Cu.
Cousinia assadii Attar	Asteraceae	**Za**	3000–3400	Th.-Cu.
Cousinia bachtiarica Boiss. & Hausskn.	Asteraceae	Za	2400–3000	Umb., Th.-Cu.
Cousinia barbeyi C.Winkl.	Asteraceae	Za	1570–2400	Th.-Cu.
Cousinia calcitrapa Boiss.	Asteraceae	Za, Ke	2100–3000	Th.-Cu.
Cousinia canescens DC.	Asteraceae	Za, Az	1850–2500	Th.-Cu.
Cousinia denaensis Attar & Djavadi	Asteraceae	Za	1800–2900	Oak W., Th.-Cu.
Cousinia gracilis Boiss.	Asteraceae	Za	2700–2800	Th.-Cu.
Cousinia iranshahriana Attar & Maroofi	Asteraceae	Za	2000–2800	Th.-Cu.
Cousinia kotschyi Boiss.	Asteraceae	Za, Ke	1200–3000	M Grass., Umb., Th.-Cu.
Cousinia longifolia C. Winkl. & Bornm.	Asteraceae	Za, Ke	3000–3400	Th.-Cu.
Cousinia oligocephala Boiss.	Asteraceae	**Za**	3200–3700	Th.-Cu.
Crepis heterotricha DC.	Asteraceae	Az, Al, Za, Ke	3000–4300	Th.-Cu., Alp.-Subn. Scree
Echinops ceratophorus Boiss.	Asteraceae	Za, Ke	1500–2800	Th.-Cu.
Echinops iranshahrii Rech.f.	Asteraceae	**Za**	1600–1800	Oak W.
Echinops kotschyi Boiss.	Asteraceae	**Za**	3000–3200	Th.-Cu.
Echinops macrophyllus Boiss. & Hausskn. var. *laciniatus* Mozaff.	Asteraceae	Za	1000–2500	Oak W.
Echinops macrophyllus Boiss. & Hausskn. var. *papillosus* Mozaff.	Asteraceae	Za, Al	1600–2500	Oak W.
Echinops mosulensis Rech.f. var. *papillosus* Mozaff.	Asteraceae	Za	500–2500	Oak W.
Echinops viscidulus Mozaff.	Asteraceae	Za	1500–3200	Umb., Th.-Cu.
Erigeron daenensis Vierh.	Asteraceae	Za	3700–4300	Chasm., Subn. Scree
Helichrysum artemisioides Boiss & Hausskn	Asteraceae	Za	1400–2100	Th.-Cu.
Helichrysum oligocephalum DC.	Asteraceae	Za, Al, Az	1600–3600	Umb., Th.-Cu.
Iranecio paucilobus (DC.) B. Nord.	Asteraceae	Za, Al, Ke	1800–3600	Th.-Cu., Alp. Scree
Lactuca denaensis N. Kilian & Djavadi	Asteraceae	**Za**	3600–4000	Chasm.

Species	Family	Distribution	Elevation range (m)	Main Habitat
Lactuca polyclada Boiss.	Asteraceae	Za	3200–3400	Th.-Cu.
Myopordon persicum Boiss.	Asteraceae	Za	3800–4400	Subn. Scree
Pentanema multicaule Boiss.	Asteraceae	Za	2100–3750	Chasm.
Phagnalon persicum Boiss.	Asteraceae	Za, Ke	1700–3400	Chasm.
Picris strigosa M.Bieb. subsp. *gonicaula* (Boiss.) Lack	Asteraceae	Za, Al, Ke	1250–2800	Th.-Cu.
Psychrogeton chionophilus (Boiss.) Krasch.	Asteraceae	**Za**	3500–3700	Th.-Cu., Snowbed
Scorzonera calyculata Boiss.	Asteraceae	Za, Al, Az, Ke	1000–3000	Oak W., Th.-Cu.
Scorzonera stenocephala Boiss.	Asteraceae	Za, Al, Az, Ko	2400–3600	Th.-Cu.
Scorzonera subaphylla Boiss.	Asteraceae	Za	2700–3400	Th.-Cu.
Senecio kotschyanus Boiss.	Asteraceae	Za, Ke	3800–4200	Subn. Scree
Tanacetum dumosum Boiss.	Asteraceae	Za	2100–3300	Th.-Cu.
Tanacetum persicum (Boiss.) Mozaff.	Asteraceae	Za, Al, Az, Ke, Ko	1700–3800	Chasm.
Tanacetum polycephalum Sch.Bip. subsp. *farsicum* Podl.	Asteraceae	Za, Ke	1500–3990	Th.-Cu.
Taraxacum kotschyi Soest	Asteraceae	Za	1640–2800	Chasm.
Tragopogon caricifolius Boiss.	Asteraceae	Za, Al, Az, Ke	1000–4000	Th.-Cu.
Alkanna frigida Boiss.	Boraginaceae	Za, Al	1500–3400	Oak W., Th.-Cu.
Caccinia kotschyi Boiss.	Boraginaceae	Za	1500–2500	Oak W., Chasm.
Onosma kilouyense Boiss. & Hausskn	Boraginaceae	Za, Al	1500–3500	Th.-Cu.
Onosma kotschyi Boiss.	Boraginaceae	Za, Al, Ke	1220–3150	Th.-Cu.
Onosma platyphylla H.Riedl	Boraginaceae	Za	1400–3000	Th.-Cu.
Onosma stenosiphon Boiss.	Boraginaceae	Za, Al, Ke, Ko	3000–4000	Th.-Cu.
Trichodesma aucheri DC.	Boraginaceae	Za, Ke	1500–3050	Th.-Cu.
Aethionema alpinum Moazzeni & Noroozi	Brassicaceae	Za, Ke	3000–4000	Alp. Scree
Aethionema umbellatum (Boiss.) Bornm.	Brassicaceae	**Za**	3900–4300	Subn. Scree
Didymophysa aucheri Boiss.	Brassicaceae	Za, Al, Az, Ko	3000–4800	Subn. Scree
Dielsiocharis kotschyi (Boiss) O.E. Schulz	Brassicaceae	Za, Ke, Al, Az, Ko	1300–4000	Chasm.
Fibigia umbellata (Boiss.) Boiss.	Brassicaceae	Za, Al, Ke	1900–3900	Th.-Cu.
Micrantha multicaulis (Boiss.) Dvorak	Brassicaceae	Za	1200–3600	Th.-Cu.
Physoptychis gnaphalodes Boiss.	Brassicaceae	Za, Al, Az, Ke	3000–4700	Alp.-Subn. Scree
Pseudocamelina aphragmodes (Boiss.) N. Busch	Brassicaceae	Za	3000–4200	Alp.-Subn. Scree
Pseudocamelina glaucophylla (DC.) N. Busch	Brassicaceae	Za, Al, Az, Ke	2500–3800	Alp.-Subn. Scree
Zerdana anchonioides Boiss.	Brassicaceae	Za,Ke	3500–4400	Subn. Scree
Campanula luristanica Freyn	Campanulaceae	Za	2000–2800	Chasm.
Acanthophyllum crassifolium Boiss.	Caryophyllaceae	Za, Al, Az	1100–3000	Th.-Cu.
Arenaria minutissima Rech.f. & Esfand.	Caryophyllaceae	Za, Ke	3700–4200	Alp.-Subn. Scree
Arenaria persica Boiss.	Caryophyllaceae	Za, Ke	3000–4200	Th.-Cu.
Bufonia kotschyana Boiss.	Caryophyllaceae	Za, Al, Az	1600–3100	Th.-Cu.
Bufonia macrocarpa Ser.	Caryophyllaceae	Za, Al	1300–3000	Th.-Cu.
Dianthus austroiranicus Lemperg	Caryophyllaceae	Za, Ke	1600–2300	Th.-Cu.
Dianthus denaicus Assadi	Caryophyllaceae	**Za**	2600–3700	Th.-Cu.
Dianthus orientalis Adams subsp. *aphanoneurus* Rech.f.	Caryophyllaceae	Za	2000–4140	Th.-Cu., Chasm.
Dianthus orientalis Adams subsp. *scoparius* (Fenzl ex Boiss.) Bornm.	Caryophyllaceae	Za	2300–2500	Th.-Cu., Chasm.
Dianthus stenocephalus Boiss.	Caryophyllaceae	Za	2100–2500	Th.-Cu.
Minuartia sublineata Rech.f.	Caryophyllaceae	Za, Az	1650–4200	Chasm.
Silene albescens Boiss.	Caryophyllaceae	Za	1315–3000	Th.-Cu.
Silene daenensis Melzh.	Caryophyllaceae	Za	3000–4400	Alp.-Subn. Scree
Silene elymaitica Bornm.	Caryophyllaceae	Za	1700–3350	Chasm.
Silene farsistanica Melzh.	Caryophyllaceae	Za	1800–3000	Th.-Cu.
Silene gynodioica Ghaz. subsp. *glandulosa* Melzh.	Caryophyllaceae	Za, Ko	1900–3500	Th.-Cu.
Silene gynodioica Ghaz. subsp. *peduncularis* (Fenzl ex Boiss.) Melzh.	Caryophyllaceae	Za, Az, Ke	1150–3500	Th.-Cu.
Silene nurensis Boiss. & Hausskn.	Caryophyllaceae	Za, Ke	3600–4400	Subn. Scree
Silene persica Boiss.	Caryophyllaceae	Za	2400–3500	Chasm.
Silene rhynchocarpa Boiss.	Caryophyllaceae	Za	2000–3000	Chasm.
Silene tragacantha Fenzl ex Boiss.	Caryophyllaceae	**Za**	3800–4000	Th.-Cu.
Colchicum wendelboi K. Persson	Colchicaceae	Za	850–3000	Wetland
Convolvulus urosepalus Pau	Convolvulaceae	Za	2500–3450	Umb.
Sedum callichroum Boiss.	Crassulaceae	Za	1300–3000	Oak W.
Sedum kotschyanum Boiss.	Crassulaceae	Za, Ke	2100–4000	Alp.-Sub. Scree
Cephalaria juncea Boiss.	Dipsacaceae	Za, Az	1500–3100	Oak W.
Pterocephalus persicus Boiss.	Dipsacaceae	Za, Ke	1600–3100	Oak W.
Euphorbia hebecarpa Boiss.	Euphorbiaceae	Za, Ke, Az	3000–3800	Th.-Cu.
Euphorbia plebeia Boiss.	Euphorbiaceae	Za	2000–2500	Oak W., Th.-Cu.
Astragalus argyrostachys Boiss.	Fabaceae	Za	1650–2400	Oak W.
Astragalus brachycalyx Fisch. subsp. *eriostylus* (Boiss. & Hausskn.) Zarre	Fabaceae	Za	2000–3200	Th.-Cu.

Species	Family	Distribution	Elevation range (m)	Main Habitat
Astragalus campylanthus Boiss.	Fabaceae	Za, Ke	1550–3100	Th.-Cu.
Astragalus cephalanthus DC.	Fabaceae	Za, Ke	1150–3000	Th.-Cu.
Astragalus chalaranthus Boiss. & Hausskn.	Fabaceae	**Za**	2200–3050	Th.-Cu.
Astragalus chartostegius Boiss. & Hausskn.	Fabaceae	Za	2500–4000	Th.-Cu.
Astragalus cyclophyllon Beck	Fabaceae	Za, Az	1000–2800	Oak W.
Astragalus daenensis Boiss.	Fabaceae	Za, Ke	3300–4200	Alp.-Subn. Scree
Astragalus fragiferus Bunge	Fabaceae	Za	1700–3600	Th.-Cu.
Astragalus horridus Boiss.	Fabaceae	Za	2400–3700	Th.-Cu.
Astragalus ibicinus Boiss. & Haussk.	Fabaceae	Za	1600–3250	Th.-Cu.
Astragalus inexspectatus Maassoumi & Podlech	Fabaceae	Za	2400–3000	Umb., Th.-Cu.
Astragalus ischredensis Bunge	Fabaceae	Za, Ke	1000–3100	M Grass.
Astragalus johannis Boiss.	Fabaceae	Za, Ke	1300–3780	Oak W., Th.-Cu.
Astragalus lateritiiformis Zarre	Fabaceae	Za	2102–3100	Th.-Cu.
Astragalus maassoumii Podl.	Fabaceae	Za	2000–2400	Th.-Cu.
Astragalus managettae Sirj. & Rech.f.	Fabaceae	Za	1800–2200	Oak W.
Astragalus melanodon Boiss.	Fabaceae	Za	3500–4400	Alp.-Subn. Scree
Astragalus microphysa Boiss.	Fabaceae	Za, Ke	1900–3800	Th.-Cu.
Astragalus murinus Boiss.	Fabaceae	Za	2500–3900	Th.-Cu.
Astragalus myriacanthus Boiss.	Fabaceae	Za, Ke	2000–3800	Th.-Cu.
Astragalus plagiophacos Maassoumi & Podlech	Fabaceae	Al	2200–3900	Th.-Cu.
Astragalus plebejus Boiss.	Fabaceae	Za	1800–3650	Th.-Cu.
Astragalus ptychophyllus Boiss.	Fabaceae	Za	1600–3000	Oak W., Th.-Cu.
Astragalus quinquefoliolatus Bunge	Fabaceae	Za	1600–2400	Th.-Cu.
Astragalus rhodosemius Boiss. & Hausskn.	Fabaceae	Za, Az, Ke	1300–3500	Th.-Cu.
Astragalus sisakhtianus Podlech & Maassoumi	Fabaceae	**Za**	2400–2500	Oak W.
Astragalus spachianus Boiss. & Buhse	Fabaceae	Za, Ke	1200–3300	Th.-Cu., Oak W.
Astragalus sphaeranthus Boiss.	Fabaceae	Za	2200–3800	Th.-Cu.
Astragalus susianus Boiss. subsp. *sericeus* Tietz	Fabaceae	Za	1210–3355	Th.-Cu.
Astragalus susianus Boiss. subsp. *susianus*	Fabaceae	Za	1400–3040	Th.-Cu.
Astragalus tenuiscapus Freyn & Bornm.	Fabaceae	Za, Ke	2450–3950	Umb.
Astragalus turgidus Podlech	Fabaceae	Za	2700–3900	Alp. Scree
Astragalus zerdanus Boiss.	Fabaceae	Za	3500–4400	Subn. Scree
Cicer spiroceras subsp. *spiroceras* Jaub. & Spach	Fabaceae	Za, Ke	1500–3700	Umb.
Cicer tragacanthoides Jaub. & Spach	Fabaceae	Za, Al, Ke, Ko	2600–4000	Alp.-Subn. Scree
Hedysarum criniferum Boiss.	Fabaceae	Za	1600–3000	Th.-Cu.
Onobrychis melanotricha Boiss.	Fabaceae	Za, Al	900–3200	Th.-Cu., Oak W.
Oxytropis chrysocarpa Boiss.	Fabaceae	Za, Al, Ko	1900–3000	Oak W.
Vicia ciceroidea Boiss.	Fabaceae	Za, Al, Az	2600–4200	Alp.-Subn. Scree
Vicia kotschyana Boiss.	Fabaceae	Za	2400–4100	Alp.-Subn. Scree
Ajuga austro-iranica Rech. f.,F	Fabaceae	Za	400–3600	Chasm.
Ajuga chamaecistus Ging. ex Benth.	Lamiaceae	Za, Al, Az, Ko	1200–2800	M Grass.
Dracocephalum kotschyi Boiss.	Lamiaceae	Za, Al, Az	1500–3500	M Grass., Umb.
Dracocephalum surmandinum Rech.f.	Lamiaceae	Za	3000–3900	Th.-Cu.
Mentha longifolia (L.) Hudson var. *kermanensis* Rech.f.	Lamiaceae	Za, Al, Ke	1300–3800	Wetland
Nepeta glomerulosa Boiss.	Lamiaceae	Za, Al, Ke, Ko	200–3800	Umb.
Nepeta kotschyi Boiss.	Lamiaceae	Za	1100–2930	Umb.
Nepeta lasiocephala Benth.	Lamiaceae	Za, Ke	3500–4400	Subn. Scree
Nepeta macrosiphon Boiss.	Lamiaceae	Za, Az	1800–3800	Umb.
Nepeta oxyodonta Boiss.	Lamiaceae	Za, Ke	1000–3300	Chasm.
Nepeta schiraziana Boiss.	Lamiaceae	Za, Al, Ko	1500–3000	Oak W.
Phlomis anisodonta Boiss. subsp. *occidentalis* Jamzad	Lamiaceae	Za	950–3300	Th.-Cu.
Phlomis persica Boiss.	Lamiaceae	Za, Al	0–2800	Oak W., Th.-Cu.
Phlomoides adenantha Jaub. & Spach	Lamiaceae	Za, Ke	150–2900	Oak W.
Satureja bachtiarica Bunge	Lamiaceae	Za, Ke	1550–3000	Chasm.
Scutellaria multicaulis Boiss.	Lamiaceae	Za, Al, Ke	3000–4200	Alp.-Subn. Scree
Stachys acerosa Boiss.	Lamiaceae	Za, Ke	1700–3500	Th.-Cu.
Stachys ixodes Boiss. & Hausskn. ex Boiss.	Lamiaceae	Za	1700–2860	Chasm.
Stachys obtusicrena Boiss.	Lamiaceae	Za, Ke	3500–4200	Subn. Scree
Stachys persepolitana Boiss.	Lamiaceae	Za, Ke	800–2600	Chasm.
Stachys pilifera Benth.	Lamiaceae	Za	1700–3350	Th.-Cu.
Thymus daenensis Celak.	Lamiaceae	Za, Al, Az, Ke	1100–3100	Th.-Cu.
Linum persicum Ky. ex Boiss.	Linaceae	Za	1900–3200	Th.-Cu.
Alcea iranshahrii Pakravan	Malvaceae	**Za**	2400–2600	Umb.
Fraxinus angustifolia Vahl. subsp. *persica* (Boiss.) Azadi	Oleaceae	Za	850–2500	Oak W.
Acantholimon flexuosum Boiss. & Hausskn. ex Bunge	Plumbaginaceae	Za, Al, Ke	1600–3000	Th.-Cu.
Acantholimon melananthum Boiss.	Plumbaginaceae	Za	2500–3500	Th.-Cu.
Acantholimon oliganthum Boiss.	Plumbaginaceae	Za, Ke	1600–3500	Th.-Cu.

Species	Family	Distribution	Elevation range (m)	Main Habitat
Acantholimon tomentellum Boiss.	Plumbaginaceae	Za	3100–4200	Alp.-Subn. Scree
Bromus frigidus Boiss. & Hausskn.	Poaceae	Za	3500–4200	Alp.-Subn. Scree
Colpodium violaceum (Boiss.) Griseb.	Poaceae	Za	3000–3400	Snowbed
Elymus gentryi (Melderis) Melderis var. *ciliatiglumis* Assadi	Poaceae	**Za**	2500–3000	Th.-Cu.
Elymus zagricus Assadi	Poaceae	**Za**	2800–2900	Th.-Cu.
Piptatherum denaense Hamzehee & Assadi	Poaceae	**Za**	3200–3300	Th.-Cu.
Polygonum aridum Boiss. & Hausskn.	Polygonaceae	Za	1700–2800	Th.-Cu.
Rheum persicum Los.	Polygonaceae	Za	1650–2200	Umb.
Primula gaubaeana Bornm.	Primulaceae	Za, Ke	700–2800	Chasm.
Dionysia bryoides Boiss.	Primulaceae	Za	1850–3200	Chasm.
Dionysia diapensiifolia Boiss.	Primulaceae	Za	1000–2500	Chasm.
Dionysia revoluta Boiss. subsp. *canescens* (Boiss.) Wendelbo	Primulaceae	Za, Ke	1600–3300	Chasm.
Dionysia revoluta Boiss. subsp. *revoluta*	Primulaceae	Za, Ke	1700–3700	Chasm.
Dionysia termeana Wendelbo	Primulaceae	**Za**	2680–3500	Chasm.
Dionysia zagrica Grey-Wilson	Primulaceae	**Za**	2050–2850	Chasm.
Delphinium saniculifolium Boiss.	Ranunculaceae	Za, Ke	1700–2700	Umb.
Ranunculus elymaiticus Boiss. & Hausskn.	Ranunculaceae	Za	2200–4200	Snowbed
Rhamnus cornifolia Boiss. & Hohen. var. *cornifolia*	Rhamnaceae	Za, Az	1700–3700	Chasm.
Rhamnus cornifolia Boiss. & Hohen. var. *denudata* Bornm.	Rhamnaceae	Za	2400–3000	Chasm.
Amygdalus elaeagnifolia Spach subsp. *elaeagnifolia*	Rosaceae	Za, Ke	1300–3467	Th.-Cu.
Amygdalus elaeagnifolia Spach subsp. *leiocarpa* (Boiss.) Browicz	Rosaceae	Za, Ke	1600–3400	Th.-Cu.
Amygdalus haussknechtii (C.K.Schneider.) Bornm.	Rosaceae	Za	1400–2900	Oak W.
Cerasus brachypetala Boiss. var. *bornmuelleri* (C. K. Schneid.) Browicz	Rosaceae	Za	2100–3000	Chasm.
Cerasus brachypetala Boiss. var. *brachypetala* Boiss.	Rosaceae	Za	2100–3600	Chasm.
Cerasus microcarpa (C.A.Mey.) Boiss. subsp. *diffusa* (Boiss. & Hausskn.) Browicz	Rosaceae	Za, Al	800–2400	Oak W.
Cotoneaster persicus Pojark.	Rosaceae	Za, Ke	1000–3300	Oak W.
Potentilla elvendensis Boiss. et Hohen.	Rosaceae	Za	2200–2800	Th.-Cu.
Potentilla flaccida Th. Wolf	Rosaceae	Za, Al	2600–3750	Snowbed
Potentilla lignosa Willd. ex D. F. K. Schltdl	Rosaceae	Za, Al	2000–3200	Chasm.
Potentilla nuda Boiss.	Rosaceae	Za, Al, Az, Ke	2000–3900	Snowbed
Potentilla nurensis Boiss. & Hausskn.	Rosaceae	Za, Az	1650–3350	Wetland
Pyrus glabra Boiss.	Rosaceae	Za	1578–2600	Oak W.
Asperula fragillima Boiss. & Hausskn. ex Boiss.	Rubiaceae	Za	1800–3300	Chasm.
Asperula glomerata (M.Bieb.) Griseb. subsp. *condensata* (Ehrend.) Ehrend.	Rubiaceae	Za	3200–3500	Umb.
Asperula glomerata (M.Bieb.) Griseb. subsp. *dasycarpa* Ehrend. & Schönb.-Tem.	Rubiaceae	Za	1500–3500	Umb.
Asperula glomerata (M.Bieb.) Griseb. subsp. *filiformis* (Bornm.) Ehrend. & Schönb.-Tem	Rubiaceae	Za, Ke	3000–4200	Alp.-Subn. Scree
Asperula rechingeri Ehrend. & Schönb.- Tem	Rubiaceae	Za	2000–3900	Umb., Th.-Cu.
Crucianella gilanica Trin. subsp. *glauca* (A. Rich ex D.C.) Ehrend.	Rubiaceae	Za	1530–3204	Chasm.
Galium anguineum Ehrend & Schönb.-Tem.	Rubiaceae	Za	2150–4000	Wetland
Galium pseudokurdicum (Ehrend.) Schönb.-Tem.	Rubiaceae	Za	3500–4200	Alp.-Subn. Scree
Galium schoenbeck-temesyae Ehrend.	Rubiaceae	**Za**	2400–2900	Chasm.
Rubia albicaulis Boiss.	Rubiaceae	Za, Ke	1300–2800	Umb.
Rubia pauciflora Boiss.	Rubiaceae	Za	3000–4200	Alp.-Subn. Scree
Salix issatissensis Maassoumi, Moeeni & Rahimin.	Salicaceae	Za, Ke	1800–2500	Wetland
Scrophularia crassiuscula Grau	Schrophulariaceae	Za	1300–3300	Chasm.
Scrophularia subaphylla Boiss.	Schrophulariaceae	Za, Al, Az, Ke	3000–4150	Alp.-Subn. Scree
Verbascum austroiranicum Hub.-Mor.	Schrophulariaceae	**Za**	1900–2400	Oak W.
Verbascum hasarense Freyn & Bornm.	Schrophulariaceae	Za, Ke	2400–3600	Th.-Cu.
Veronica kurdica Benth. subsp. *filicaulis* (Freyn) M. A. Fischer	Schrophulariaceae	Za, Ke	3000–4300	Th.-Cu., Subn. Scree
Veronica rubrifolia Boiss. subsp. *rubrifolia*	Schrophulariaceae	Za, Al, Ke	1800–3000	Snowbed, Th.-Cu.
Ulmus boissieri Graudz	Ulmaceae	Za, Ke	1300–2600	Oak W.

Results and discussion

Endemicity and biogeography

Of the 242 Iranian endemic taxa recorded from the study area, a total of 22 taxa (21 species, 1 variety; Table 1) are restricted to Dena Mts, 122 taxa (105 species, 10 subspecies, 7 varieties; Table 1) are endemic to Zagros as a whole, and 120 taxa (104 species, 13 subspecies, 3 varieties) are shared with outher mountain ranges of the Iranian Plateau (Figure 6, Table 1). From these 120 taxa, 84 taxa are also present in Yazd-Kerman, 51 taxa in Alborz, 37 taxa in the Azerbaijan Plateau, and 15 taxa in Kopet Dagh-Khorassan (Figure 6). Thus, Dena Mts have the strongest floristic affinity to the closest mountain range, the Yazd-Kerman massif. The elevational belt of 2200–2600 m a.s.l. has the richest endemic diversity. Number of endemic species decrease gradually at both lower and higher elevations (Figure 7). From the 22

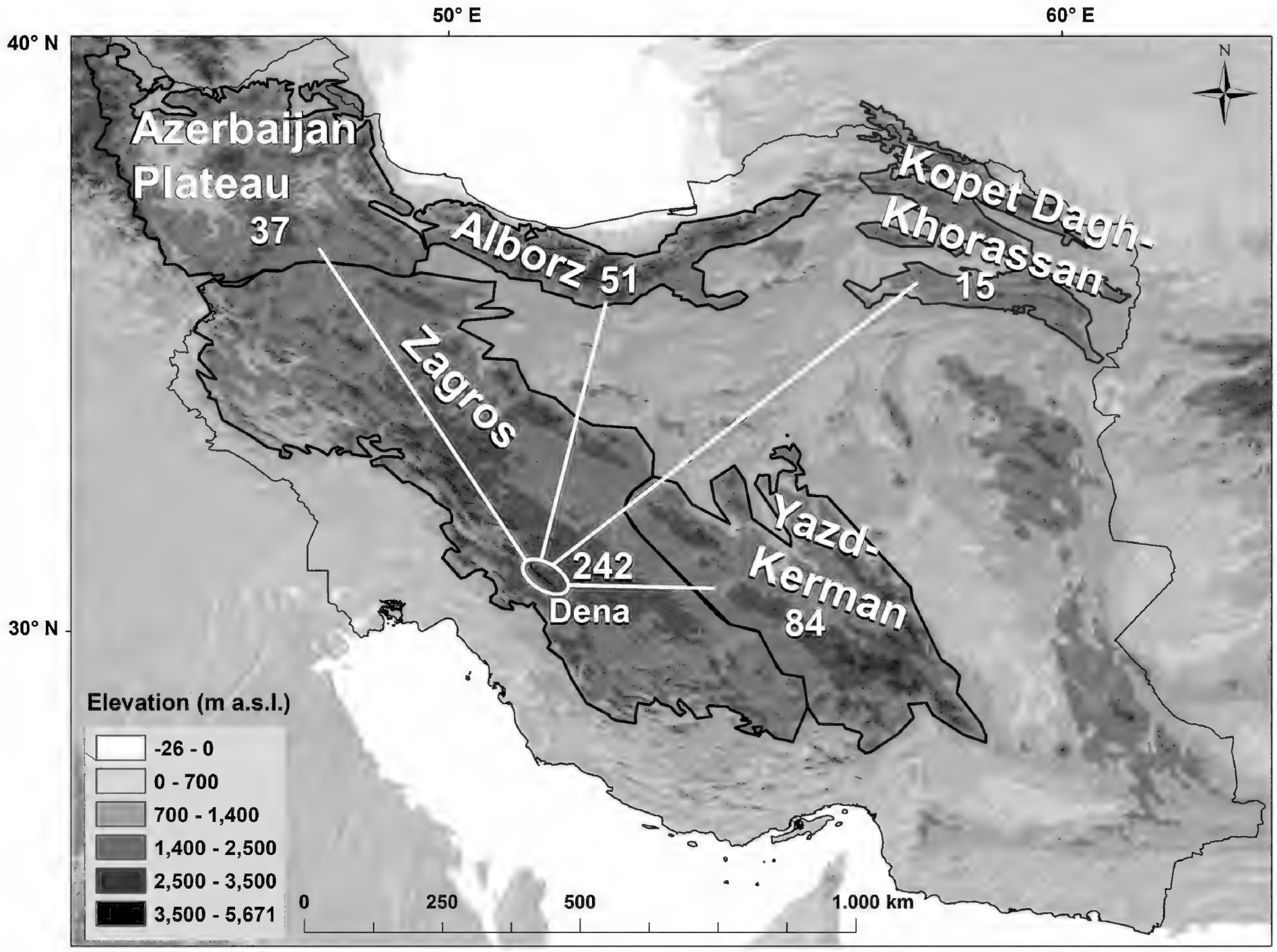

Figure 6. Floristic relationships between Dena Mts and other mountain ranges of Iran (areas of endemism), based on the endemic flora of Iran (the numbers written in each area are taxa shared with Dena Mts).

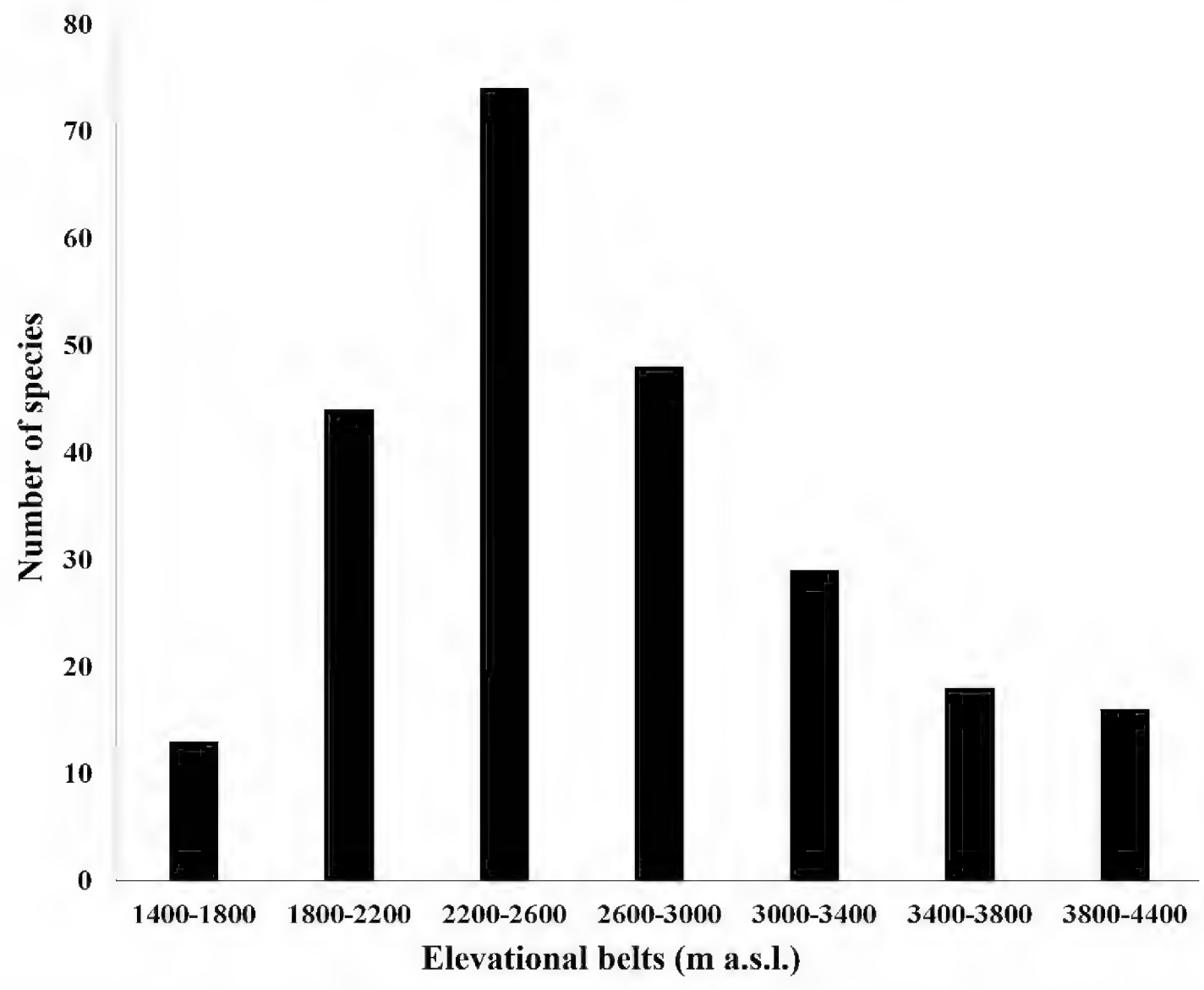

Figure 7. Number of endemic species in different elevational belts in Dena Mts. High number of endemics are concentrated in mid-elevational belts.

Table 2. List of species reaching the subnival zone of Dena Mts (elevation above 4100 m a.s.l.). Al: Alborz; Az: Azerbaijan Plateau; Ke: Yazd-Kerman; Ko: Kopet Dagh-Khorassan; Za: Zagros.

Taxon	Family	Distribution range	Type from Dena Mts
Semenovia dichotoma (Boiss.) Manden.	Apiaceae	Iran (Za)	Kotschy 1842
Crepis heterotricha DC.	Asteraceae	Iran (Az, Al, Za, Ke)	
Erigeron daenensis Vierh.	Asteraceae	SE Anatolia, Iran (Za)	Kotschy 1842
Myopordon persicum Boiss	Asteraceae	Iran (Za)	Kotschy 1842
Psychrogeton amorphoglossus (Boiss.) Novopokr.	Asteraceae	Irano-Anatolia to C Asia	Kotschy 1842
Arnebia euchroma (Royle) I. M. Johnst.	Boraginaceae	Iran (Za, Ke) to Himalaya	
Didymophysa aucheri Boiss.	Brassicaceae	Iran (Za, Az, Al)	
Dielsiocharis kotschyi Boiss.	Brassicaceae	Iran (Za, Az, Al, Ke)	
Draba aucheri Boiss.	Brassicaceae	Iran and C Asia	
Graellsia saxifragifolia (DC.) Boiss.	Brassicaceae	Iran, Hindu Kush	
Physoptychis gnaphalodes Boiss.	Brassicaceae	Iran (Za, Al, Az, Ke, Ko)	
Pseudocamelina aphragmodes (Boiss.) N. Busch	Brassicaceae	Iran (Za)	
Zerdana anchonioides Boiss.	Brassicaceae	Iran (Za, Ke)	
Arenaria balansae Boiss.	Caryophyllaceae	Anatolia and Iran	
Arenaria persica Boiss.	Caryophyllaceae	Iran (Za, Ke)	
Arenaria minutissima Rech. f. & Esfand.	Caryophyllaceae	Iran (Za, Ke)	
Minuartia sublineata Rech.f.	Caryophyllaceae	Iran (Za, Az)	
Silene daenensis Melzh.	Caryophyllaceae	Iran (Za)	
Chenopodium foliosum Asch.	Chenopodicaceae	Casmopolite	
Euphorbia aucheri Boiss.	Euphorbiaceae	Irano-Anatolia region, Hindu Kush	
Astragalus melanodon Boiss.	Fabaceae	Iran (Za)	Kotschy 1842
Astragalus zerdanus Boiss.	Fabaceae	Iran (Za)	
Onobrychis cornuta (L.) Desv.	Fabaceae	SW Asia	
Vicia ciceroidea Boiss.	Fabaceae	Iran (Za, Al, Az)	Kotschy 1842
Nepeta lasiocephala Benth.	Lamiaceae	Iran (Za)	Kotschy 1842
Scutellaria multicaulis Boiss.	Lamiaceae	Iran (Za, Al, Ke)	
Stachys obtusicrena Boiss.	Lamiaceae	Iran (Za, Ke)	
Gagea cf. alexeenkoana Micsz.	Liliaceae	Caucasus, Iran	
Acantholimon tomentellum Boiss.	Plumbaginaceae	Iran (Za)	
Bromus frigidus Boiss. & Hausskn.	Poaceae	Iran (Za)	Kotschy 1842
Elymus longearistatus (Boiss.) Tzvelev	Poaceae	Irano-Anatolian region	
Piptatherum laterale (Regel) Roshev.	Poaceae	From Anatolia to Central Asia and Himalaya	
Polygonum serpyllaceum Jaub. & Spach	Polygonaceae	Iran, Hindu Kush	Kotschy 1842
Potentilla flaccida Th.Wolf ex Bornm.	Rosaceae	Iran (Za, Al)	
Asperula glomerata (M.Bieb.) Griseb. subsp. *filiformis* (Bornm.) Ehrend. & Schönb.-Tem.	Rubiaceae	Iran (Za, Ke)	
Galium pseudokurdicum (Ehrend.) Schönb.-Tem.	Rubiaceae	Iran (Za) , Iraq	Kotschy 1842
Rubia pauciflora Boiss.	Rubiaceae	Iran (Za)	
Scrophularia subaphylla Boiss.	Schrophulariaceae	Iran (Za, Al, Az, Ke) , Iraq	Kotschy 1842
Veronica kurdica Benth. subsp. *filicaulis* (Freyn) M. A. Fischer	Scrophulariaceae	Iran (Za, Ke)	

taxa endemic to the Dena Mts, five have a mean elevational distribution between 1600 and 2500 m a.s.l., 12 taxa between 2500 and 3500 m a.s.l., and five taxa above 3500 m a.s.l.

The subnival vegetation types are dominated by scree and rocks and are very open, the vegetation having a maximum cover of 20%. Most of the 38 taxa reaching the subnival zone of Dena Mts (elevations above 4100 m a.s.l.) are endemics of the Iranian Plateau (68%), and from those, 42% are endemic of Zagros and Yazd-Kerman, and 21% are endemic of Zagros (Table 2). As only ca. 10% of the plant taxa recorded from Dena Mts (1200 taxa; Jafari Kokhedan 2003) are endemic to Zagros, the high rate of endemism for the subnival flora confirms previous findings that the rate of endemism is considerably higher in alpine and subnival habitats compared to lower elevations (Irl et al. 2015; Steinbauer et al. 2016; Noroozi et al. 2019b).

Description of new sytaxonomic units

We recorded a total of 33 species in 19 plots. The species richness ranged from 3 to 11 species per plot. The two clusters of the first TWINSPAN division level were considered as associations embedded in a new alliance that is proposed for Central and Southern Zagros. Based on the DCA ordination diagram (Figure 8), the associations are well separated from each other. We describe two new associations under a new alliance.

***Galion pseudokurdici* all. nov.** (Table 3)

Type (holotypus hoc loco): *Zerdanetum anchonioidis* ass. nov. (see below)

Character species: *Astragalus melanodon* (Figure 5A), *Bromus frigidus* (Figure 5B), *Galium pseudokurdicum* (Figure 5D), *Stachys obtusicrena* (Figure 5F).

This alliance is only known from the subnival zone of Dena Mts. Most of the character species of this unit are distributed in South and Central Zagros and in the Yazd-Kerman mountains. *Astragalus melanodon* is restricted to Central and Southern Zagros, *Bromus frigidus* and *Galium pseudokurdicum* are endemics of Zagros, and *Stachys obtusicrena* is an endemic of Zagros and Yazd-Kerman mountains. Therefore, this alliance could likely

Table 3. Relevés of scree vegetation of the subnival zone classified in *Didymophyso aucheri-Dracocephaletea aucheri* (character species highlighted in brown). The two associations *Aethionemetum umbellati* ass. nov (character species in cells with blue shading) and *Zerdanetum anchonioidis* ass. nov. (character species in cells with green shading) are classified in the alliance *Galion pseudokurdici* all. nov. (character species in cells with violet shading). Two last columns are the synoptic table (syn. Tab.) presenting the constancy (in %) and fidelity (phi value × 100) of the species in each association.

Class	***Didymophyso aucheri-Dracocephaletea aucheri* Noroozi et al. 2014**																			**Syn. Tab.**	
Alliance	***Galion pseudokurdici* all. nov.**																			**Constancy (Fidelity)**	
Association	**Ass. 1 *Aethionemetum umbellati* ass. nov.**										**Ass. 2 *Zerdanetum anchonioidis* ass. nov.**									**1**	**2**
Relevé Nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
Elevation (m)	4084	4084	4094	4103	4106	4280	4278	4291	4249	4013	4280	4226	4218	4190	4189	4171	4164	4165	4162		
Aspect	SW	SW	SW	SW	SW	SW	SW	S	NE	S	NE	N	N	NE	NE	NE	E	NE	N		
Slope (°)	35	35	35	35	40	30	30	30	25	40	30	15	20	30	10	25	15	15	10		
Vegetation cover%	15	20	15	15	10	10	5	2	15	20	15	10	10	25	15	15	20	20	35		
Scree%	85	80	85	80	90	90	90	90	85	80	70	40	30	60	70	35	80	70	40		
Soil%	-	-	-	-	-	-	5	5	-	-	15	-	-	10	5	-	-	-	10		
Rock%	-	-	-	5	-	-	-	-	-	-	-	50	60	5	10	50	-	10	15		
Species richness	8	11	8	7	6	6	3	3	7	9	6	9	10	4	6	11	10	6	9		
Aethionema umbellatum		+	+			+	+	+		+										60 (66)	
Nepeta lasiocephala			+	1	1	1	1	2	1	1										80 (82)	
Silene daenensis	+	+	+	+	+				+	2							+			70 (60)	11
Zerdana anchonioides												1	1		+	1		+			56 (62)
Erigeron daenensis												+	+			+					33 (45)
Myopordon persicum															2			1			22 (35)
Astragalus zerdanus											+		+						+		33 (45)
Veronica kurdica subsp. *filicaulis*												+	+								22 (35)
Arenaria persica																1	2		2		33 (45)
Piptatherum laterale									1			1	+	1	+	+	1		+	10	78 (68)
Bromus frigidus	1	1	2	+	+	1			2		1	+	1	+		+	+		2	70	78 (9)
Galium pseudokurdicum	2	2	1	1	1	+	+		1	1		1	1	1		1	+	+		90 (28)	67
Astragalus melanodon	1	2								2	1						+	1	+	30	44 (15)
Stachys obtusicrena	+		+												1		+	+		20	33 (15)
Physoptychis gnaphalodes	+	+			1					2			+	2	1	1	2	2	1	40	78 (38)
Elymus longearistatus	+	1	1	2	1			+	1	2					+		+			80 (58)	22
Euphorbia aucheri		+	1	+						1										40 (50)	
Psychrogeton amorphoglossus				+								+				+				10	22 (17)
Potentilla flaccida						+			+										+	20 (12)	11
Dielsiocharis kotschyi												+				+					22 (35)
Scrophularia subaphylla																+					11 (24)
Arnebia euchroma																	+				11 (24)
Crepis heterotricha											2										11 (24)
Chenopodium foliosum		+																		10 (23)	
Draba aucheri													r						+		22 (35)
Gagea cf. alexeenkoana						+													1	10	11 (2)
Arenaria minutissima																+					11 (24)
Onobrychis cornuta												+	+								22 (35)
Polygonum serpyllaceum		+									1									10	11 (2)
Pseudocamelina aphragmodes										1										10 (23)	
Rubia pauciflora											+										11 (24)
Scutellaria multicaulis		+																		10 (23)	
Acantholimon tomentellum	+																			10 (23)	

be found in similar habitats of Zagros as a whole and of the Yazd-Kerman mountains.

This alliance fits well under the class *Didymophyso aucheri-Dracocephaletea aucheri* Noroozi et al. 2014 (Tables 3, 4). This class was described from the high alpine and subnival scree vegetation types of Alborz and mountains of NW Iran, together with two orders and three alliances (Table 4): *Didymophysetalia aucheri* (with one alliance, *Didymophysion aucheri*) and *Physoptychio gnaphalodis-Brometalia tomentosi* (with two alliances, *Erigerontion venusti* and *Elymo longearistati-Astragalion macrosemii*). Additional data and studies from other parts of the Zagros and Yazd-Kerman mountains are needed to clarify if our newly described alliance belongs to one of the mentioned orders, or if a new order should be described. Ecological characters like elevational range, steepness, the composition of soil, screes and stones, and also physiognomy of the communities and species richness in the new alliance are closer to *Didymophysion aucheri* from Central Alborz (see Noroozi et al. 2014).

***Aethionemetum umbellati* ass. nov.** (Figure 9; Table 3)

Type relevé (holotypus hoc loco): Table 3, relevé 10

Character species: *Aethionema umbellatum* (Figure 9A), *Nepeta lasiocephala* (Figure 9B), *Silene daenensis* (Figure 9C).

Differential species: *Euphorbia aucheri* (Figure 5C).

This unit can be found on steep slopes (with an average inclination of 33°, and a range of 24–40°) that are mostly south- to west-exposed. The ground is mostly covered

Table 4. Synoptic table of the scree communities in N Iran and Dena Mts. Values are percentage constancies. The constancy values of character species of syntaxa are shaded, and the constancy values of character species of the class present in the newly described alliance are given in bold.

Mountains	**Alborz and NW Iran**			**Dena**
Alliance number	**All1**	**All2**	**All3**	**All4**
Number of relevés	23	69	63	19
***Didymophysion aucheri* (All1)**				
Achillea aucheri	39	.	2	.
Veronica aucheri	26	.	2	.
Galium aucheri	52	.	.	.
Veronica paederotae	30	.	.	.
Senecio vulcanicus	22	.	.	.
Erysimum elbrusense	30	.	5	.
Cerastium purpurascens	39	.	5	.
***Erigerontion venusti* (All2)**				
Draba bruniifolia	.	29	.	.
Alopecurus aucheri	.	22	.	.
Nepeta menthoides	.	25	.	.
Tripleurospermum caucasicum	.	33	.	.
Sesleria phleoides	.	22	.	.
Galium hyrcanicum	.	41	.	.
Erigeron caucasicus	.	62	.	.
Pedicularis caucasica	.	25	.	.
Minuartia glandulosa	.	26	.	.
Koeleria eriostachya	.	38	.	.
Festuca alaica	4	75	3	.
***Elymo longearistati-Astragalion macrosemii* (All3)**				
Nepeta racemosa	.	.	24	.
Astragalus macrosemius	.	.	57	.
***Galion pseudokurdici* all. nov. (All4)**				
Bromus frigidus	.	.	.	74
Galium pseudokurdicum	.	.	.	79
Astragalus melanodon	.	.	.	37
Stachys obtusicrena	.	.	.	26
Didymophyso-Dracocephaletea				
Physoptychis gnaphalodes	**1**	**16**	**17**	**58**
Euphorbia aucheri	**4**	**.**	**24**	**21**
Elymus longearistatus	**.**	**.**	**60**	**53**
Didymophysa aucheri	96	32	.	.
Dracocephalum aucheri	48	35	32	.
Bromus tomentosus	13	70	78	.
Alopecurus textilis	22	32	.	.
Asperula glomerata	30	.	40	.
Ziziphora clinopodioides	.	49	25	.
Poa araratica	4	49	37	.
Helichrysum psychrophilum	4	32	8	.

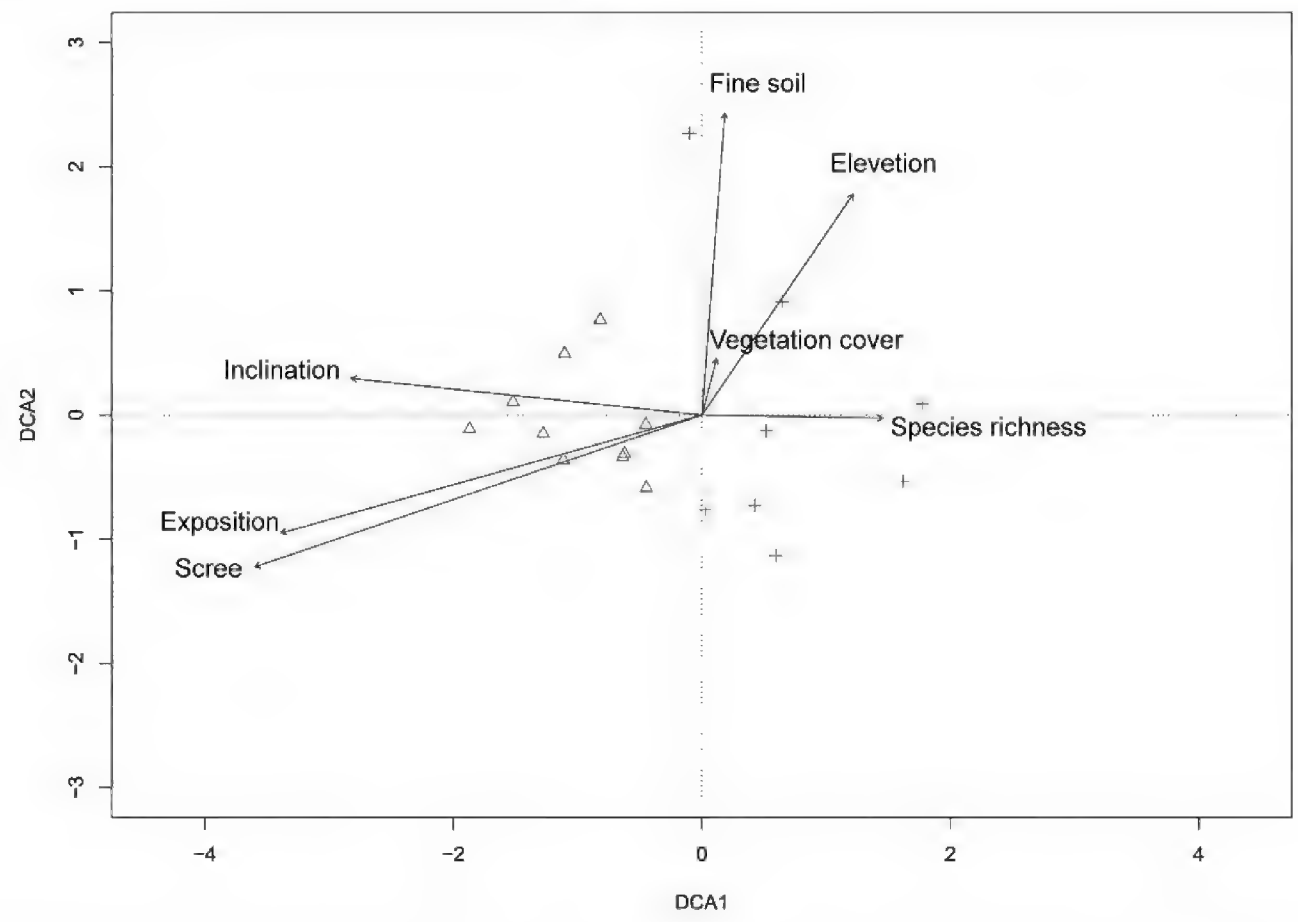

Figure 8. DCA ordination of the plots with environmental variables and vegetation features. *Aethionemetum umbellati* (triangle), *Zerdanetum anchonioidis* (square).

by scree and gravel (ca. 85%) and the vegetation cover is accordingly sparse (ca. 13%). The species richness of this association ranges from three to 11 (on average seven) species per relevé. This association is endemic to Dena Mts. *Aethionema umbellatum* and *Nepeta lasiocephala* are local endemics, whereas *Silene daenensis* is an endemic of the Zagros mountain range.

***Zerdanetum anchonioidis* ass. nov.** (Figure 10; Table 3)

Type relevé (holotypus hoc loco): Table 3, relevé 13

Character species: *Astragalus zerdanus* (Figure 10A), *Erigeron daenensis* (Figure 10B), *Myopordon persicum* (Figure 10C), *Veronica kurdica* subsp. *filicaulis*, *Zerdana anchonioides* (=*Sterigmostemum anchonioides*; Figure 10D).

Figure 9. New association *Aethionemetum umbellati* and its character species. **A)** *Aethionema umbellatum* (4200 m a.s.l.). **B)** *Nepeta lasiocephala* (4300 m a.s.l.). **C)** *Silene daenensis* (4200 m a.s.l.).

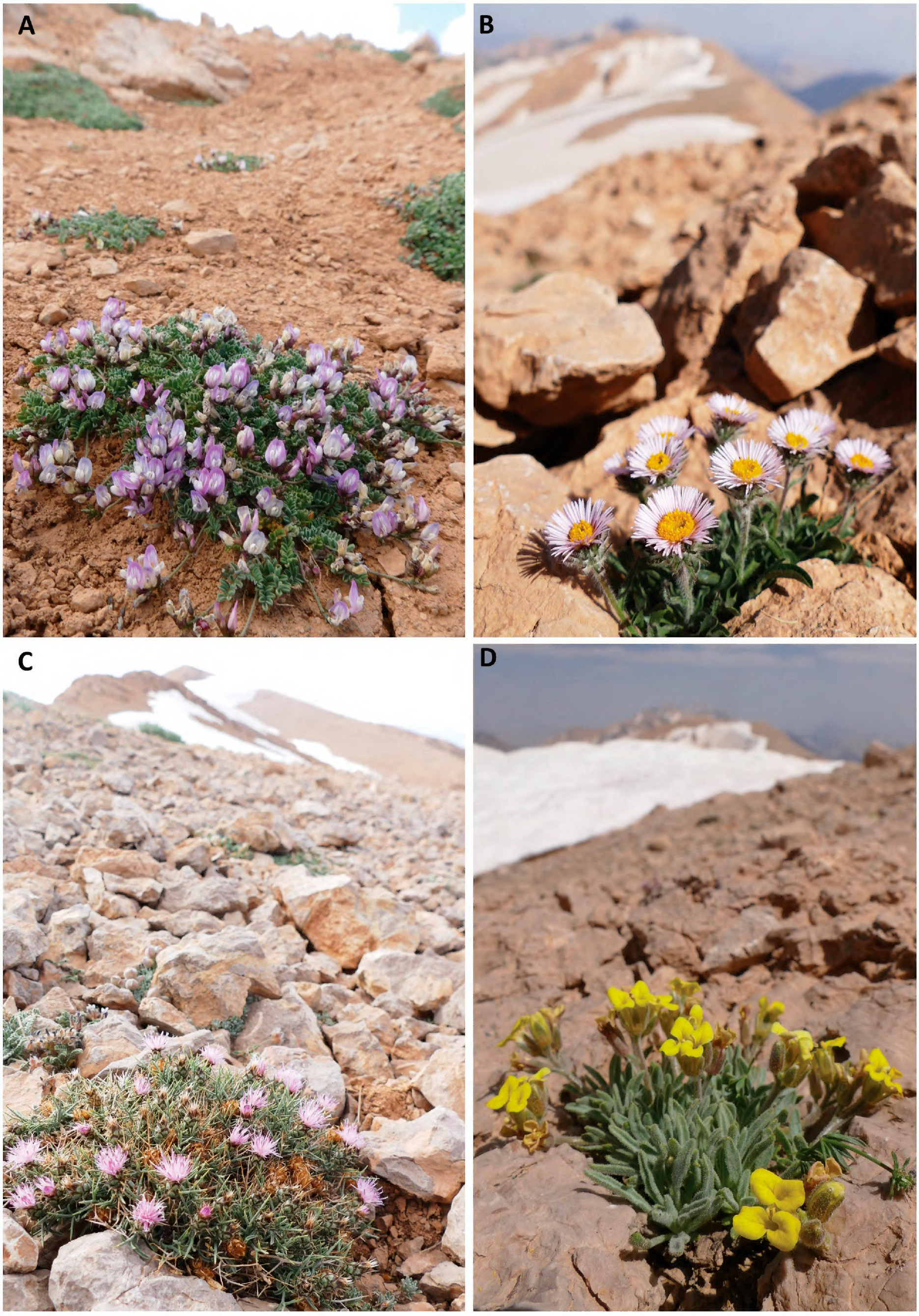

Figure 10. New association *Zerdanetum anchonioidis* and its character species. **A)** *Astragalus zerdanus* (4150 m a.s.l.). **B)** *Erigeron daenensis* (4250 m a.s.l.). **C)** *Myopordon persicum* (4200 m a.s.l.). **D)** *Zerdana anchonioides* (4300 m a.s.l.).

Differential species: *Arenaria persica*, *Piptatherum laterale*.

This unit is mostly found on north- to north-eastern-exposed slopes with an average inclination of ca. 20° (range from 10 to 30°). This association occurs on stony and scree grounds with, compared to the previous community, a lower proportion of scree (ca. 55%) and a higher proportion of rocks (on average 28%) and open soil (ca. 10%). The average vegetation cover of the association is ca. 20% and species richness ranges from four to 11 (average of eight) species per relevé. *Zerdana anchonioides* is an endemic of Southern Zagros and the Yazd-Kerman mountain range. *Astragalus zerdanus*, *Erigeron daenensis* and *Myopordon persicum* are endemic elements of Zagros. *Veronica kurdica* subsp. *filicaulis* is an endemic taxon of Zagros and Yazd-Kerman. Based on the distribution of the characteristic species, the geographic extent of this association is expected to cover the subnival zone of Southern and Central Zagros.

Conservation concerns

Dena Mts harbor a high amount of endemic species. Although the number of endemic species is also high in mid-elevational belts, the proportion of endemics increases with increasing elevation. Consequently, our newly described communities of the subnival zone harbor a high number of range-restricted species. Shrinking of alpine and subnival habitats and the loss of cold-adapted species of the high mountains have been recorded, and also have been predicted in biodiversity scenarios for the 21st century as the result of a general upward shift of plant species under a warmer climate (Chen et al. 2011; Engler et al. 2011; Pauli et al. 2012). The subnival zone, with a very high proportion of endemic and range-restricted species in South-West Asia (Noroozi et al. 2011; Noroozi et al. 2019b), may be the most fragile habitat under the impact of ongoing climate change due to the absence of alternative habitats for the cold-adapted species to move into. Therefore, subnival species of Dena Mts, which are already restricted to habitats near the summits of the mountain range (in a narrow elevation belt above 4100 m a.s.l. with small area size), are at high risk of population size reduction or even extinction. Moreover, like other high mountains of Iran, overgrazing is a big problem for the natural vegetation types of the high mountains. Most of the big herds of the lowlands and montane zone move to the high elevations in summertime and concentrate in small areas of alpine habitats. Usually, the size of the herds exceed the capacity of these vegetation types, and the natural species composition and range-restricted species are highly endangered (Noroozi et al. 2008; Bagheri et al. 2022). Dena Mts have the highest summit of the entire Zagros and are attractive for mountaineering and tourism. Although Dena Mts lie within a protected area, this will not prevent shrinking of alpine habitats due to the ongoing global warming, or degradation of these ecosystems due to overgrazing or tourism. Consequently, strong attention to increase the efficiency of the protection and to reduce other anthopogenic activities in high elevations of this mountain system in particular and of the entire South-West Asian mountains in general is highly recommended.

Data availability

All data are presented in the paper.

Author contributions

J.N. planned the research, conducted the field sampling, identified the species, and analyzed the data, A.T. identified the species and contributed to data analyzing, M.S. contributed to fieldwork and data collection, and G.M.S. contributed to writing and editing. All authors have read and agreed to the published version of the manuscript.

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